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16. ABSTRACT

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COMPARATIVE LIMNOLOGY AND BIOTA OF MINE SPOILS PONDS IN COLORADO

STEVEN P. CANTON

ABSTRACT.—Physico-chemical and biotic parameters were investigated from June 1977 to May 1978 in coal strip-mine ponds in Colorado which differed in age and in the proportion of drainage derived from the mine. There were no discernible effects of mine drainage on temperature, dissolved oxygen, hardness, pH, acidity, alkalinity, calcium, iron, orthophosphate, or the organic content of the substrate. In contrast to spoils ponds in eastern and midwestern states, acid mine drainage was not observed. Total dissolved solids, nitrate, and sulfate values were higher in the spoils ponds than in the control pond. Net zooplankton abundance was lowest in the youngest spoils pond, but the standing crop of benthos exhibited a progressive decrease from the youngest spoils pond to the control pond. Certain zooplanktonic and benthic species were rare or absent in the youngest spoils pond. Colonization phenomena (age and distance from a source of colonizers) are postulated as responsible, in part, for the faunal differences between ponds, although higher levels of nitrate, sulfate, and TDS in the spoils ponds may provide adverse conditions for certain species. If these data are typical of the western energy region, they suggest the potential for development of recreational lakes as a part of reclamation practices.

The deleterious effects of drainage from coal strip-mines on aquatic systems have been well documented in the eastern and midwestern United States (e.g., Appalachian Regional Commission, 1969; Roback and Richardson, 1969; Warner, 1973). Strip-mine lakes receiving drainage from the high-sulfur coal mines of those regions contain acidic waters which require extended recovery periods before supporting a normal aquatic biota (Parsons, 1964, 1977; Campbell and Lind, 1969; Smith and Frey, 1971; King et al., 1971; Riley, 1977).

Little work has been done to assess the effects on aquatic systems of drainage from the low-sulfur coal mines of the western United States (Reed, 1975). Surface mining activity has been conducted for over 30 years at the Edna Mine in northwestern Colorado. Although low in sulfur compared to eastern coal, the 2.4% sulfur content and 30.8% iron oxide in the ash of Edna mine coal are the highest values for coals studied in Colorado (Deurbrouck, 1970). Yet a 2-year study failed to indicate any distinctly deleterious effects of the Edna Mine on an adjacent stream (Canton and Ward, 1978). The apparent lack of adverse effects was attributed to the presence of a buffer strip between the mine spoils and the stream, and to climatic, hydrologic, and geochemical conditions (Ward et al., 1978).

Strip mining at the Edna Mine leaves the overburden in large spoil piles which are presently being regraded. Drainage from the spoils forms ponds at the base of the coal seam against the highwall of the pit. In June 1977 research was undertaken on these spoils ponds which receive drainage directly from the mine. The purpose of the research reported herein was to investigate the limnological conditions and biota of spoils ponds of different ages which were differentially influenced by mine drainage.

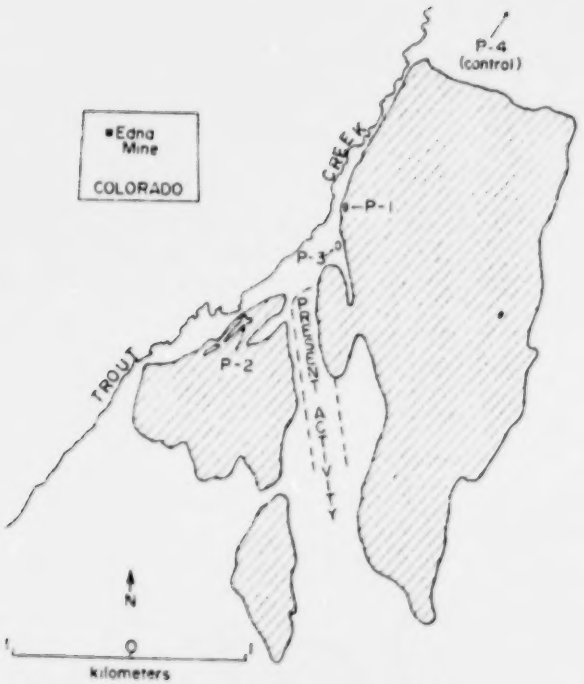

FIG. 1.—Pond locations in relation to Edna Mine spoils (crosshatched) and present mining activity, the control pond, P4, is in an adjacent watershed.

STUDY AREA.—Edna mine coal is mined from the Wadge seam in the Williams Fork Unit of the Mesa Verde group. The Williams Fork formation overburden consists primarily of shale, sandy shale, and thin beds of sand (McWhorter et al., 1975).

Four pond study sites were established to correspond to a gradient of mining effects (Fig. 1). Two of the ponds received all of their drainage from the mine, but differed in age; one pond received only partial drainage from mine spoils, and the control pond received no drainage from mining activity.

Pond P1, which was approximately 10 years old, formed where water accumulated against a highwall. The surface area was approximately 0.02 ha; maximum depth was 1.0 m. The bottom of the pond was covered with the alga *Chara globularis* throughout the summer and fall.

Pond P2, which was approximately 30 years old, was situated at the base of a highwall where drainage from the area of oldest mining activity accumulated. This is the largest pond, with an area of approximately 0.39 ha and a maximum depth of 3.8 m. Aquatic macrophytes generally were sparse, although *Carex*, *Eleocharis*, and *Typha* grew along the edge. *Potamogeton* became abundant in late summer-early autumn, but was limited to the shallow areas.

Pond P3 is an old stock pond formed by damming an intermittent drainage. Although not located directly in the spoils, P3 received some drainage from the mine. This pond was similar in area and depth to P1. Throughout the summer, over 90% of the pond surface was covered with a floating mat of *Spirogyra*. Due to the input of groundwater and the insulating effect of the algae, the water under the mat was at times 5 to 10°C cooler than the surface water.

Pond P4, the control pond, is located 5 km northeast of P1. This pond also is an old stock pond formed by damming a small drainage, but it is not affected by mining activity. The pond had an

TABLE 1.—*Physico-chemical parameters from ponds associated with coal mining in northwestern Colorado. Mean values with ranges in parentheses (June 1977-May 1978).*

Parameter	Ponds			
	P1	P2	P3	P4 (control)
Temperature (°C) 10 cm	11.0	12.6	11.2	14.7
	(0.0-20.0)	(0.0-23.0)	(0.0-17.5)	(2.0-24.0)
Dissolved O_2 (mg l)	15.6	11.1	12.7	15.0
	(8.2-29.4)	(7.6-16.2)	(8.5-17.5)	(6.4-29.6)
Bound CO_2 (mg l $CaCO_3$)	56.5	36.6	108.2	77.0
	(27.5-94.0)	(11.5-52.0)	(50.0-145.5)	(38.5-124.0)
pH (median)	7.4	7.4	7.4	7.6
	(7.1-8.1)	(6.8-7.7)	(7.0-7.5)	(7.0-8.1)
Nitrate (mg l)	16.31	0.55	0.89	0.11
	(6.38-26.3)	(0.0-2.63)	(0.03-1.0)	(0.0-0.48)
Orthophosphate (mg l)	0.15	0.07	0.17	0.30
	(0.0-0.34)	(0.0-0.11)	(0.13-0.21)	(0.0-0.89)
Total dissolved solids (mg l)	3811	1770	2632	547
	(2501-5626)	(1129-2561)	(2122-2963)	(254-758)
Loss on ignition (mg l)	1079	112	749	193
	(662-1725)	(204-604)	(645-1001)	(116-758)
Percentage of TDS	28	23	28	35

area of 0.05 ha and a maximum depth of 1.5 m. Dense growths of *Myriophyllum* occurred during summer. The emergents *Carex* and *Eleocharis* and the floating plant *Lemna* were present along the edges.

The ponds were located at similar elevations (2133 - 2170 m a.s.l.), and were ice covered from November-March during the year of study.

METHODS.—The four ponds were sampled monthly from June 1977 through May 1978 except December and February (and January at P4).

Water temperature was measured with a thermister at 10-cm depth intervals. Dissolved oxygen levels were measured in the field using the azide modification of the Winkler titration method. The pH was determined in the field using comparator discs. One-liter water samples were transported to the laboratory in an ice chest. Bound CO_2 (methyl orange alkalinity) was measured by titration with HCl using methyl orange as an indicator (Pennak, 1977). Orthophosphate and nitrate levels were determined bimonthly using colorimetric methods summarized by Lind (1974).

Total dissolved solids were analyzed bimonthly by filtration of 0.5 l water samples through cellulose discs (0.45 μm apertures) and subsequent evaporation of the filtrate in a sand bath at 60°C (Ward, 1974). The residue was fired at 600°C in a muffle furnace to obtain loss on ignition values. Water samples collected before and after spring runoff were subjected to more detailed analyses by the Colorado State University Chemistry Department.

Substrate samples were collected with an Ekman grab in June 1977 from the 0.5-m depth contour. Organic content was determined using wet digestion with dichromic acid; the hydrometer method was used for particle size analysis. The Colorado State University Soil Testing Laboratory performed the analyses.

Net zooplankton samples were taken by filtering 20 l of pond water from a depth of 10 to 20 cm through the bucket of a Judav plankton trap (mesh aperature = 64 μm). Samples were preserved with 80% ethanol. In the laboratory 1-ml aliquots were transferred to a Sedgwick-Rafter counting cell with a Hensen-Stempel pipet and the zooplankters were enumerated at 100×.

Benthic macroinvertebrates were collected by taking three Ekman grab samples from each pond. The samples were combined, stored on ice, and returned to the laboratory. The samples were washed through a 250 μm mesh sieve and preserved in 5% formalin. The organisms were sorted from the debris and placed in 80% ethanol for later identification and enumeration.

RESULTS AND DISCUSSION.—*Physico-chemical Parameters.*—The temperatures of the ponds generally were similar (Table 1). Most differences were

TABLE 2.—*Selected chemical parameters of ponds associated with coal mining activity in northwestern Colorado, compared with ponds in regions of acid mine drainage.*

Parameter	Ponds							
	P1[a]	P2[a]	P3[a]	P4[a]	A1[b]	A2[c]	1958[d]	1977[e]
Acidity (mg l $CaCO_3$)	0	0	0	0	227-1920	27-55	14	0
Alkalinity (mg l $CaCO_3$)	66-180	98-113	283-316	167-282	0	0	2	80
Sulfate (mg l)	2500-3180	940-1260	1360-1500	168-250	1620-5030	108-324	560	580
Calcium (mg l)	350-360	57-304	330-340	200-300	82-233	28-79		127
Total iron (mg l)	0.03	0.13	0.09	0.11	74-272	0.11-1.88	<1.0	0.81
Manganese (mg l)	<0.001	0.001-0.21	0.002-0.069	0.001-0.011	27-95	0.79-3.18		0.02
Magnesium (mg l)	400-550	82-130	226-340	56-118	63-175	6.5-17		38.9
Sodium (mg l)	98-160	19-36	20-21	19-25	8.9-23.3	1.3-1.6		
Potassium	11.1-19	3.6-6	1.6-5.1	2.3-4	0.2-1.6	3.35-9.2		
Zinc (mg l)	<0.01	<0.01	<0.01	21.8-86	0.56-1.56			

[a]Colorado State Univ. Chemistry Dept., 29 April 1977 and 29 July 1977. [b]34-year-old mine pond in Missouri (Campbell and Lind, 1969). [c]50-year-old mine pond in Missouri (Campbell and Lind, 1969). [d]10-year-old mine pond in Ohio (Riley, 1977). [e]55-year-old mine pond in Ohio (Riley, 1977).

attributable to differences in the time readings were taken. The ponds were well exposed to wind action and thermal stratification normally was not apparent. Some stratification was observed at P3 in the summer when the algal mat formed a nearly opaque layer just below the surface.

Dissolved oxygen values also were similar between ponds; variations in mean values were primarily a function of the degree of supersaturation encountered. At P3 samples were taken under the algal mat when present.

The highest mean value for bound CO_2 was recorded from P3 (108 mg l $CaCO_3$), a pond not directly associated with mining activity. The control pond, P4, also had a relatively high value of 77 mg l $CaCO_3$. The ponds receiving drainage directly from the mine, P1 and P2, had the lowest values for bound CO_2 (57 and 37 mg l $CaCO_3$ respectively).

According to Pennak (1971), the waters of P2 would be classified as "medium," P1 and P4 as "hard," and P3 as "very hard." It is not possible to account for the large seasonal variations observed, which appear unrelated to the influence of mine drainage. The control pond (P4) exhibited autumn values nearly seven times greater than those encountered during spring.

Acid mine drainage was not evident in any of the ponds. Median pH value ranged from 7.4 to 7.6; the lowest value was 6.8 (Table 1). The youngest spoils pond (P1), which receives all drainage directly from the mine, exhibited pH values from 7.1 to 8.1. This is in contrast to eastern mine spoils ponds where pH may remain below 4.0 50 years after the cessation of mining (Campbell and Lind, 1969). In the ponds in Colorado there was no relationship between pH levels and either age or extent of mining influence.

Nitrate levels were higher in ponds receiving mine drainage than in the control pond. In the semi-arid climate of this region, surface mining increases leaching of soluble salts (Ward et al., 1978). It appears that nitrate levels remain high for a number of years. The youngest spoils pond (P1) exhibited consistently high nitrate values (mean = 16.34 mg l). Nitrate levels in the mine spoils, as measured by saturated paste analysis, were similar throughout the mined area (McWhorter et al., 1975) and cannot explain the high levels at P1. Orthophosphate values, however, did not exhibit any discernible relationship with age or degree of mining effects. The highest levels were found in the control pond.

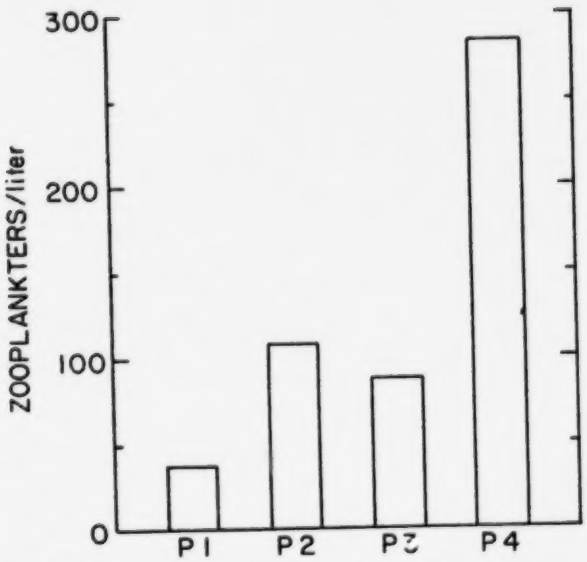

FIG. 2.—Annual mean densities (organisms l^{-1}) of net zooplankton.

Mean values of total dissolved solids (TDS) were three to seven times greater in the spoils ponds than the control pond (Table 1). The highest value (3811 mg l^{-1}) occurred in the youngest spoils pond. TDS thus appears to be influenced by watershed disturbance from mining in a manner similar to nitrate. Analysis of variance for the TDS values indicated a significant difference ($P < 0.01$) between the ponds with a linear trend from the highest values in the youngest pond to the lowest in the control. Loss on ignition averaged 23 to 35% of the total dissolved solids.

None of the physico-chemical parameters exceeded levels designated as safe for aquatic life (U.S. EPA, 1976).

To provide comparative data, selected chemical parameters from the Colorado ponds are related to mine ponds in regions of acid mine drainage (Table 2). The Missouri ponds studied by Campbell and Lind (1969) were 34 years old (A1) and 50 years old (A3). Riley (1977) studied a pond in Ohio when it was 40 years old (1958) and when it was 55 years old (1973). There is a striking difference between the Colorado ponds and those in areas of acid mine drainage (AMD). Acidity was never detected in the Colorado ponds, but was still measurable (27 to 55 mg l^{-1} $CaCO_3$) 50 years after mining in A3. Alkalinity was high in all the Colorado ponds, but was not detected in A1 or A3. Only in the Ohio pond, 55 years after mining, did alkalinity values approach those of the youngest pond in Colorado (Table 2). Sulfate levels were high (940 to 3180 mg l^{-1}) in the Colorado ponds associated with mining activity. However, the high levels of sulfates in the Colorado ponds are due to the gypsum ($CaSO_4 \cdot H_2O$) found in the overburden rather than the oxidized sulfides associated with AMD (McWhorter et al., 1975). The gypsum

and the shaley nature of the overburden accounted for the generally high levels of calcium in the Colorado ponds (57 to 364 mg l). The Colorado ponds had low levels of iron (0.03 to 0.14 mg l) comparable to mine ponds 50 to 55 years old. Other differences in ionic composition between the ponds in Colorado and those in areas of AMD generally reflect differences in regional geology.

The particle size distribution and organic content of the sediment in the four Colorado ponds were generally similar. The particle size distribution at P1 was divided evenly among the sand, silt, and clay fractions. The substrate at P2 was predominately sand (49%). The two ponds not directly associated with mining, P3 and P4, had predominately silt sediments (57% and 41%, respectively). The relative contribution of organic matter was similar at all ponds, ranging from 6.7% at P1 to 11.4% at P2.

Net Zooplankton.—Annual mean density of zooplankton ranged from 39 organisms l at P1 to 283 organisms l at P4. The differences in mean density values between ponds (Fig. 2) were not statistically significant (AOV: $P < 0.05$) due to wide seasonal variation in numbers.

Protozoa were present in all ponds, but abundant only at P2, where *Difflugia* and *Ceratium* accounted for 88% of the total density. Rotifers were also collected in all ponds, but were abundant only at P4, where they accounted for 29% of the total zooplankton density. *Keratella quadrata* and *Filinia longiseta* were the predominant species. Cladocerans were important only at P3 and P4, the ponds not directly associated with mining activity. A single specimen of *Bosmina longirostris* was the only cladoceran collected from P1 during the year of study. Cladocerans were most abundant at P4, where they accounted for only 17% of the zooplankton density. *Ceriodaphnia reticulata* was the most abundant species. Limnetic copepods were represented by a single species, *Cyclops bicuspidatus thomasi*, which was important in all ponds except P2. Ponds of this region should contain one or two species of *Diaptomus* unless vertebrate predators are present (S. I. Dodson, pers. comm.). However, fish were absent from all ponds except P2. The absence of calanoid copepods is inexplicable and apparently unrelated to mining.

The fewest zooplankton taxa (10) were found at the youngest spoils pond (P1). The control pond, P4, had the greatest number of taxa (18). The trend in species richness was statistically significant (AOV: $P < 0.01$).

Benthic Macroinvertebrates.—Standing crop (density and biomass) of the benthic invertebrates exhibited a marked pattern (Fig. 3), with the greatest standing crop at P1, the youngest spoils pond, and the lowest standing crop at the control pond, P4. The large standing crop at P1 was due to large numbers of tubificid worms and chironomids. The standing crop at P4 was dominated by amphipods, mayflies, leeches, and odonates.

Oligochaeta were present in all ponds, but abundant only in P1 and P3. At pond P1, oligochaetes comprised 44% of the total macroinvertebrate density and 65% of the biomass. Oligochaetes comprised 45% of the density and 52% of the biomass at P3. *Limnodrilus hoffmeisteri* was the predominant species. Hirudinea were collected from all ponds, although only rarely in P1; *Helobdella stagnalis* was the predominant species in all cases. Molluscs

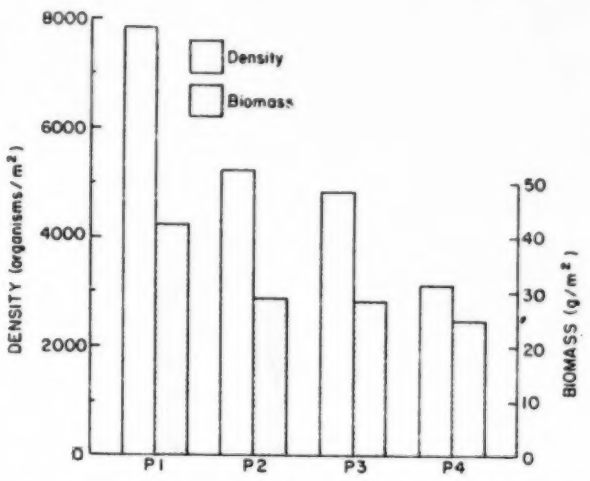

FIG. 3.—Annual mean density (organisms m^{-2}) and biomass (g wet wt m^{-2}) of macrobenthos.

were present in all the ponds, but abundant only at P2, where they accounted for 13% of the density and 40% of the invertebrate biomass, due primarily to large numbers of *Pisidium variabile*. The abundance of molluscs in the spoils pond is important since they are generally not found in areas of acid mine drainage (Dieffenbach, 1974). Amphipods were represented by a single species, *Hyalella azteca*, which was never collected at P1, the youngest spoils pond, even though it was found consistently in the other mine ponds having similar water chemistry. Amphipods were most abundant in the control pond, P4, accounting for 21% of the density and 14% of the biomass.

Ephemeropterans, which are intolerant of acid drainage (Napier and Hummon, 1976), were collected at all ponds, but were abundant only at P4, where they accounted for 38% of the total density and 24% of the biomass due to large numbers of *Caenis*. Odonata were collected in all ponds, but were abundant only at P2 (6% of the biomass) and P4 (15%). *Neoneura* and *Enallagma* were the predominant genera. Trichoptera occurred infrequently except at P2, where they accounted for 11% of the invertebrate biomass, due to the presence of the large caddisfly larvae *Phryganea cinerea* and *Limnephilus*. Caddisflies were never collected at P1, the youngest pond in the mine. Aquatic beetles (Coleoptera) were present in all ponds, but abundant only at P1 and P4. Coleopterans comprised 2% of the invertebrate density and 4% of the invertebrate biomass at P1, due to the abundance of *Haliplus* spp. and *Hydroporus tenebrosus*. Coleoptera were most numerous at P4, accounting for 6% of the density and 7% of the biomass due to the greater abundance of *Haliplus* spp. Species of *Haliplus* often are found in strip-mine ponds (Brigham and Sanderson, 1974), which are used as refugia in areas with little standing water.

Dipterans were abundant in all ponds. They comprised 49% of the macroinvertebrate density at P1, due to the abundance of chironomids. Chironomids were also shown to be major members of the benthos in strip-mine lakes in Indiana (Smith and Frey, 1971). At P2, the dipterans comprised 29% of the density and 9% of the biomass due to high numbers of chironomids, *Tabanus*, and *Palpomyia*. At P3, dipterans accounted for 38% of the density and 20% of the biomass, primarily due to chironomids and ceratopogonids. The control pond (P4) exhibited the lowest relative abundance of dipterans, primarily due to decreased abundance of chironomids.

The fewest macroinvertebrate taxa were collected at P1, the youngest spoils pond, with only 25 taxa represented. The other ponds had 36 to 38 species. The greater number of species at P2, P3, and P4 was due to more species of Hirudinea, Amphipoda, Odonata, Trichoptera, and Diptera.

There were noticable differences in the fauna of the ponds. The absence of cladocerans and amphipods from the youngest pond is particularly striking. It is possible that adverse physico-chemical conditions (i.e., high TDS values) may restrict the distribution of these species. However, cladocerans were very abundant in another Colorado lake with TDS values exceeding 5,000 mg/l (Pennak, 1949). The absence of *Hyalella azteca* also may relate to high salinity, but this species is widespread throughout Colorado in waters with a wide range of TDS values (Pennak and Rosine, 1976). In fact *H. azteca* has been found in lakes with salinity values up to 25,700 mg/l (Rawson and Moore, 1944).

It is felt that the less diverse zooplankton and benthic invertebrate communities at P1 may be partly a function of colonization phenomena (sensu MacArthur and Wilson, 1967). Percentage Similarity Coefficient (Whittaker, 1975) considers both presence-absence of species and their relative abundance. This similarity index was calculated for both the zooplankton and macrobenthos of the ponds. Ponds P1 and P3 exhibited the greatest similarity in zooplankton communities (0.66). This could be explained in the context of island biogeography (MacArthur and Wilson, 1967) since pond P1, the youngest pond, would likely receive the greatest number of colonizers from the nearest source, which is P3. The similarity was greatest for the protozoans and rotifers, both of which (especially protozoans) disperse passively with the action of the wind, flying insects, and birds (Maguire, 1963; Stewart et al., 1970; Milliger et al., 1971; Solon and Stewart, 1972). The Percentage Similarity Coefficient provides additional support for the role of colonization phenomena in structuring the benthic communities of the ponds. Ponds P1 and P3 also were most similar in benthic faunal composition (0.68). Hirudinia, Amphipoda, Odonata, and Trichoptera were poorly represented in pond P1, due perhaps to low dispersal ability (e.g., Amphipoda) or lack of adequate time to reach the pond. The youngest spoils pond, P1, and P4, which is in an adjacent watershed, were the most dissimilar (0.14).

Additional studies of physico-chemical conditions and biota are needed to determine whether or not the results contained herein are typical of spoils ponds in the western energy region. These data suggest that spoils ponds have potential as recreational lakes and may provide environmental condi-

tions suitable for a variety of aquatic organisms. The feasibility of transplanting macrophytes, plankton, benthos, and fishes from local lentic habitats should be investigated as a mechanism of speeding natural colonization processes.

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